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**WILL GASEOUS DETECTORS SURVIVE
THE RAPID PROGRESS IN THE COMPETING TECHNIQUES?**

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1. INTRODUCTION

Just a glance at the program of this conference shows that gaseous detectors are still a blooming source of new instruments, as claimed in the title of my talk at the preceding Vienna Wire Chamber Conference in 1983.

Major advances have been made in solid-state detectors. High-resolution position accuracies in the domain of 3 to 20 μm are almost routine techniques with microstrip silicon detectors or charged coupled devices [1]. The solid-state drift chamber offers many promising features in this field [1]. Low-temperature devices give the prospect of lowering, by an order of magnitude, the energy resolution of solid-state detectors for very low energy radiations. But gaseous detectors still offer, at present, the only solution for radiation detectors of large surfaces, with a flexibility giving them a variety of applications, such as the imaging of vacuum-ultraviolet (VUV) light, the tracking of complex configurations of particles, the construction of large calorimeters, and so on.

In this talk, I will illustrate the possibility of further progress in gaseous detectors, taking illustrative examples from the activity of our group at CERN but I am sure that at this conference, similarly to the preceding one, many more examples of the fertility of the field will be given.

2. AMPLIFICATION OF AVALANCHES BETWEEN PARALLEL GRIDS, IN SINGLE OR MULTISTEP STRUCTURE

Multistep avalanche chambers are starting their career as ideal VUV detectors because of their capacity to provide the very large gains suitable for single-electron detection together with a suppression of the parasitic feedback effect from the photons emitted in the avalanches. They also offer the advantage of providing the possibility of operation at low pressures, in the range of 10 Torr, thus being almost insensitive to charged particles. Breskin and Majewski are pursuing this line of research in their respective laboratories. The single-step amplification of avalanches between parallel grids also has some applications. It seems that its interest for the end cap of time projection chambers (TPCs) has faded out because of unexpected difficulties of operation in magnetic fields [2]. Let me mention an interesting application for the imaging of X-rays, in a piece of work by Peisert and Sauli [3]. With X-rays of 5.9 keV they obtain an energy resolution as good as with wire chambers, with a localization of 0.2 mm (FWHM), obtained by an original method, from a single cathode. The investigation of the count-rate limitations of multistep chambers has shown that at moderate gains a count rate of $10^5/\text{mm}^2\cdot\text{s}$ can be achieved [4, 5].

Multistep chambers have also found a field of application as imaging devices for X-rays with an energy resolution improved with respect to ordinary multiwire chambers. By tuning the gas composition, a group of astrophysicists [6] showed that they can reach a resolution close to 10% FWHM at 6 keV. This group attribute this improvement to the use of Penning mixtures in the multistep structure, but another group [7] also find significant improvement of the energy resolution with non-Penning mixtures. An advantage of a multistep structure is the spreading of the electron swarm after the first step of amplification, resulting in a charge sharing between adjacent wires in the final-step wire chambers, thus permitting an obliteration of the wire structure.

3. THE MARRIAGE OF DENSE SCINTILLATORS WITH GASEOUS DETECTORS

Since the last Vienna Wire Chamber Conference a few steps have been accomplished. A calorimeter of 20 radiation lengths made of 14 layers of BaF_2 , read out by low-pressure wire chambers filled with tetrakis(dimethylamine)ethylene (TMAE), has shown that the characteristics of this new type of calorimeter are very encouraging: a time resolution of the order of 1 ns, an energy resolution of the order of 3% at 1 GeV, and a considerable resistance to radiation damage [8]. Some doubts have arisen concerning the condensation of a photosensitive liquid layer of TMAE on the

surface of the electrodes. While it is clear now that no such layer is produced by absorption at normal temperature, the question of a photosensitive liquid layer produced by condensation at a cold temperature on a cathode is still open in some minds. Anderson had confirmed the existence of such a layer in a recent unpublished test at Fermilab, while two groups present contradictory evidence at this conference. Nevertheless, quite independently from this, the overlap of the light emission spectrum from BaF_2 and of the photosensitive yield spectrum from TMAE opens the way for the combination of BaF_2 with photosensitive wire chambers, thus offering, in comparison to photomultipliers or photodiodes, the advantage of position resolution due to the specific properties of wire chambers in this respect. The prospect of combining a full efficiency for 0.511 keV γ -rays together with a good position resolution, of the order of a few millimetres, with a good time resolution, has triggered some activity in the construction of positron imaging cameras based on this principle.

4. OPTICAL IMAGING OF AVALANCHES

If avalanches are produced in a gas with a copious emission of detectable light from excited atoms it may be of interest to take a picture of the avalanches with the help of image intensifiers, instead of extracting the information by electronic methods. This is the case when extremely complex configurations render impossible the electronic retrieval with the ultimate spatial resolution allowed by wire chambers. This is the case with showers or with rings of Cherenkov radiation having a high multiplicity of points. Precisely this last application has triggered the work of a British group [9]. However, the amount of detectable light is very scarce with most of the gas mixtures used in wire chambers or parallel-plate amplifying gaps. At the same time as the British group [10] and with quite a different detector structure [11] we have now arrived at the use of the same favourable vapour: TEA (triethylamine) emits copiously in the region of 300 nm wavelength, when it is mixed with any proportion of noble gases and even when isobutane is added in moderate proportions. We obtain enough light to be seen, with an image intensifier, in a single multiwire chamber. This opens the way for many applications: it is possible to obtain the pattern from the optical image, while the pulse height on the wires and their time distribution give the additional information for a complete spatial reconstruction of the event.

We envisage applications for Ring Imaging Cherenkov counters, high density calorimeters and double β -decay of ^{36}Xe in a huge xenon counter. Figure 1 shows images obtained with a dense drift space, where cosmic-rays produce a reaction in a copper-grid structure of 1 g/cm^3 . This last structure could be interesting for a proton-decay detector. Further studies are required to find the energy resolution. The drift structure can be built in a similar way to the dense drift space used for the DELPHI calorimeter.

5. ELECTROSTATIC IMAGING

The subjects I have mentioned by no means exhaust the field of applications in which our group are active. We pursue our work on electrostatic imaging [12]. In an experiment at Fermilab, done with the help of Anderson, we could show that it is possible to collect on a mylar foil the electrons produced in liquid argon by ionizing radiations (Fig. 2). The challenge is now to develop the latent electrostatic image: a line of 80,000 electrons per centimetre, of a width of $20 \mu\text{m}$, for minimum ionizing particles. Only an electronic method would permit the localization of the electrons. We are developing this method and Fig. 3 shows a first application for the readout of diffraction patterns with a thin CF_3Br detector, where the X-rays liberate enough electrons in the gas to be easily detected when trapped on mylar. For heavily ionizing particles the most sensitive toners used in electrophotography could be the way to materialize these trajectories. The advantage of this

approach is to offer the quality of a photographic method for very complex events, combined with the possibility to gate the events with a simple grid placed at the exit of the drift space, thus permitting the selection of events produced by a high beam intensity.

While this approach has the ambition of detecting the ionization produced in dense media by charged particles without any gaseous amplification, I would like to emphasize a possible application of a preliminary study where a two-step amplification between parallel grids has permitted the individual avalanches produced by minimum ionizing particles in helium to be read out. At this conference Breskin presents a work on the detection of single photoelectrons with a two-step chamber, operated at low pressure, where minimum ionizing particles produce two ion pairs per centimetre, showing that a gain of 10^8 can be obtained in such chambers. If such a chamber should be used as the end cap of a TPC, with a magnetic field parallel to the electric one, thus reducing the diffusion, it would be easy to detect the individual avalanches stored on a dielectric surface, either by electronic methods or by using the most sensitive toners. At a time when colliders giving rise to very complex events, with very rare triggers, are envisaged, this slow method of data acquisition may be the only alternative offered for a bias-free readout of the trajectory patterns, when it is combined with an electronic readout of the pulse height of the avalanches on the anodes as a function of time.

6. TRACKING OF PARTICLE TRAJECTORIES

In the field of particle localization slow progress has been accomplished since the study of multiwire structures and drift chambers in 1968-1969, where an accuracy of $100\ \mu\text{m}$ was achieved [13, 14]. A careful study of the centroid of avalanches on a wire has resulted in the demonstration that the accuracy of measurement along a wire is practically limited only by the position fluctuations of the initial ionization electrons and not by measurement; $35\ \mu\text{m}$ accuracy had been achieved with photoelectrons having a range of about $35\ \mu\text{m}$ [15]. The latest measurements, reported at this conference by Fisher et al., with a high-pressure gas filling reducing the range of the photoelectrons, show a gain by an order of magnitude. The present progress in electronics permits this centroid digital computation to be done in less than $0.5\ \mu\text{s}$ [16].

The study of the centroid has resulted in a deeper insight into the localization of the azimuthal position of avalanches around the anode wire, with possible applications for an improved accuracy of the position of primary electron clusters. This demonstration of the localization of the avalanches between limited azimuthal angles has also been independently done by looking at the angular anisotropy of positive ions collected from the avalanche [17].

While the increase of accuracy in the localization of the trajectories has been to some extent deceptively slow when compared to the present needs, the progress has been spectacular in the architectures of detectors such as the TPC, JADE, or the UA1 central detector, where the skill and imagination of the experimental groups have been displayed to adjust the detectors to the specific physics conditions. One requirement which becomes more drastic under the present conditions of operation of colliders or storage rings is the construction of absolutely reliable high-accuracy tracking detectors. Sauli will present at this meeting our contribution to this problem with multiwire tubes providing a very high density of measuring points and I leave it to him to convince you of the interest of this approach.

I only want to point out that this multiwire tube structure can be a good solution for a standing problem in the field of gaseous detectors. So far, despite its considerable potential qualities for this purpose, the multiwire chamber has not emerged as a credible candidate for medical imaging with X-rays. Among the reasons let me mention the low level of reliability when compared with the competing imaging devices, the difficulty of reaching a counting rate sufficient for imaging in a convenient time, and the limited lifetime of chambers submitted to large rates. A tube structure, with a very high density of wires, permits most of these problems to be solved. The rate is split among a

great number of wires, thus reducing the ageing of a wire. No loss of accuracy is introduced by the large thickness of the detector since the depth of localization is known. The current division on every wire or group of wires gives the coordinate along the wire. The reliability is increased since it is easy to change a tube without disturbing the whole system. We have verified that this structure works well with xenon. A reliable detector which can handle huge rates, without ageing, with an accuracy of $2\text{ mm} \times 2\text{ mm}$ and a large surface would be a good candidate for some medical radiographic applications.

For vertex detectors these multiwire tubes are in competition with high-pressure drift chambers of various structures which will certainly be discussed at this meeting. A new development based on old ideas is making a spectacular comeback: scintillation light-guide fibres viewed by image intensifiers. They offer a redundancy adapted to the high multiplicities foreseen with the future accelerators. Their accuracy is better than that of the best gaseous detectors. They are in competition even with the solid-state detectors. Their drawback is so far the high Z and the density of the glass, which can be a physical nuisance; this may eliminate them in many cases where the great number of measuring channels they provide is not essential. For the tracking in the UA2 experiment a version with plastic scintillation fibres has been adopted, with an accuracy limited by the diameter of the fibres, which has to be at least 1 mm, for a good efficiency.

7. CONCLUSIONS

Despite nearly two decades of operation, multiwire chambers and drift chambers are a major component in most particle-physics experiments. Their use is going beyond the role of localization devices for particle trajectories. They are the basic tools for improved VUV imaging devices and new types of calorimeters, and they are far from having exhausted their potential despite the considerable progress in competitive techniques, such as solid-state detectors or imaging fibres. Many pending problems in experimental particle physics or in biophysics may still find elegant solutions based on these detectors.

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Figure captions

- Fig. 1 : Optical imaging of avalanches: cosmic-ray events. A drift space of 2.5 cm depth is filled with copper grids of 0.2 mm thickness, with square holes ($2.7 \text{ mm} \times 2.7 \text{ mm}$) and a distance of 3 mm between the centres of the holes; the copper grids are separated by insulating grids of kapton with the same structure. A potential gradient, applied to the grids, drifts the ionization electrons from the holes to a wire chamber with wires of $35 \mu\text{m}$ diameter and 4 mm spacing between them. Gas filling xenon (53%) + isobutane (39%) + triethylamine (8%). (From M. Suzuki et al., CERN, to be published.)
- Fig. 2 : Electrostatic imaging of electrons from liquid argon. The picture shows the images obtained by ionizing liquid argon with a β and α source. The electrons are collected on a mylar sheet and the image is obtained by using a positive liquid toner from Coulter Systems (Bedford, Mass.). The problem now is to visualize individual tracks.
- Fig. 3 : Electrostatic imaging from ions in gaseous freon. The X-rays are absorbed in a 2 mm layer of CF_3Br and collected on mylar. They are produced by diffraction of an 8 keV beam on a protein crystal. The readout is obtained by direct measurement of the static charges. Horizontal size: 12 cm. Vertical size: 12.5 cm. (G. Charpak, J. Lewiner and D. Morisseau, Ecole supérieure de Physique et Chimie industrielles de la Ville de Paris, unpublished results.)

Fig. 1

α

β

Fig. 2

Fig. 3